A Study to Understand the Early Life History of Snake River Basin Fall Chinook Salmon

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EXECUTIVE SUMMARY

We began a study in 2005 to document the downstream passage histories of returning PIT-tagged Snake River fall Chinook salmon *Oncorhynchus tshawytscha* adults, in part to further understand the juvenile life history strategies of passive integrated transponder (PIT) tagged fish that were never detected during their juvenile migration. We analyzed data from adults recaptured at Lower Granite Dam from September to November 1998-2005. Scale samples were read to determine age at ocean entry (subyearling or yearling). Downstream passage histories were determined to the extent possible based on available juvenile PIT-tag detections and age at ocean entry. The effects of age at ocean entry on time spent in seawater and fork length at return were also evaluated.

We analyzed data from adult returns at Lower Granite Dam for 118 fall Chinook salmon that had been tagged as subyearlings. We found that 93 (79%) of these fish had entered seawater as yearlings, and of these 93, 27 were conclusively shown to have spent their first winter as juveniles in reservoirs. The remaining 66 of these yearling ocean entrants had spent their first winter in unknown freshwater locales, with 36 having completed their juvenile migration without being detected at a dam. We deduced that most of these 66 fish likely spent their first winter in reservoirs upstream from Bonneville Dam.

We recaptured 20 adult fall Chinook salmon at Lower Granite Dam that had been tagged as subyearlings, transported during summer, and released below Bonneville Dam. Of these transported fish, 65% had entered the ocean as subyearlings and 35% as yearlings after wintering in fresh or estuarine water downstream from Bonneville Dam. We recaptured an additional 33 fish that had been tagged as subyearlings and transported during fall. Of these, 39% had entered the ocean as subyearlings and 61% as yearlings after wintering in fresh or estuarine water below Bonneville Dam.

From overall trends observed for each group analyzed, we found that subyearling ocean entrants were less likely than yearling ocean entrants to return after spending one year or less at sea (subyearlings produced fewer jacks and mini-jacks). However, after omitting jacks from consideration, yearling ocean entrants still comprised over half of the full-term adults. Full-term adults that had been yearlings at ocean entry were also similar in size or larger than full-term adults that entered the ocean as subyearlings. This finding should reduce concerns that yearling ocean entry reduces spawner size and thus fecundity.

We concluded that Snake River fall Chinook salmon juveniles employ diverse downstream passage strategies to reach the sea. This diversity should be considered when planning recovery measures, designing hydrosystem survival studies, and attempting to calculate SARs for smolts with different passage histories, particularly undetected groups of fish.

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INTRODUCTION

The National Marine Fisheries Service began annual studies in 2001 to evaluate the efficacy of transporting Snake River fall Chinook salmon *Oncorhynchus tshawytscha* from lower Snake River hydropower projects (Marsh et al. 2003, 2004a,b, 2005). Subyearlings used in these studies included both wild and hatchery fall Chinook salmon. Hatchery fish were from Lyons Ferry Hatchery (Figure 1), and all study fish were implanted with passive integrated transponder (PIT) tags (Prentice et al. 1990a).

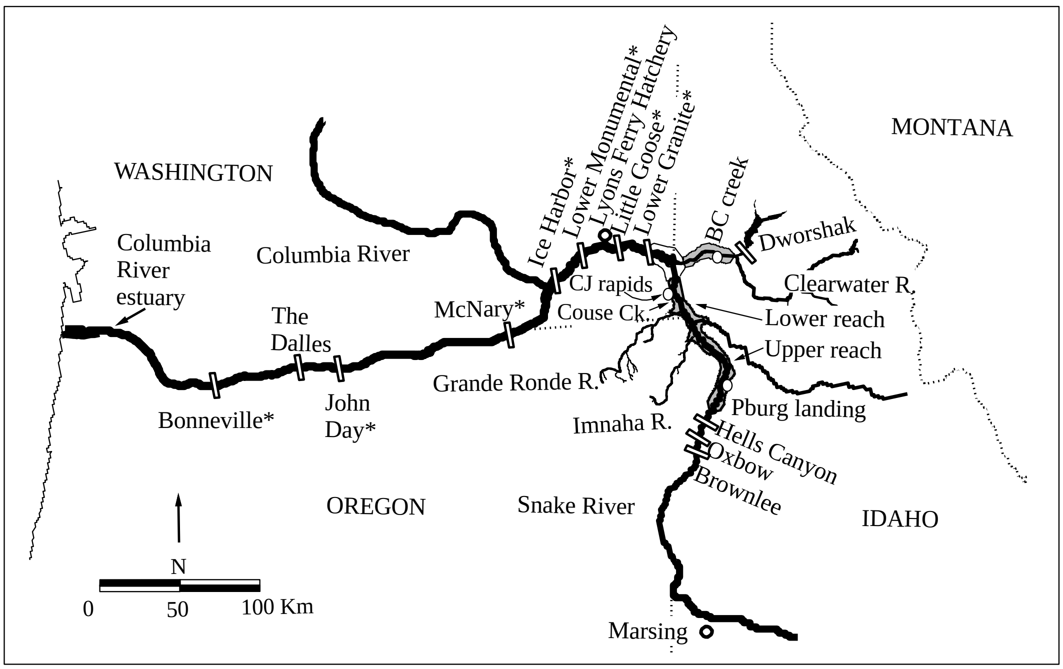

Figure 1. The Snake River and lower reaches of its tributaries (gray shaded areas) where wild fall Chinook salmon were hatched before being PIT tagged as subyearlings for life history and juvenile survival studies. Lower Granite Dam and Lyons Ferry Hatchery (open circle), where subyearlings were PIT-tagged for transportation studies are also shown. Dams with juvenile fish bypass systems and PIT-tag monitors are indicated by an asterisk.

The original study compared smolt-to-adult return rates (SARs) of transported subyearlings to those of subyearlings that migrated downstream in the Snake and Columbia Rivers without being detected in the juvenile bypass systems at dams (i.e., a non-detected inriver group). Analysis of SARs used the model developed for PIT-tagged spring Chinook salmon by Sandford and Smith (2002). This model calculates SARs for transported fish based on known transported numbers, but calculates SARs for non-detected inriver groups based on estimates of the number of these smolts that arrive at Lower Granite Dam.

An underlying biological assumption of Sandford and Smith (2002) is that after release, smolts do not discontinue active seaward movement upstream of Lower Granite Dam, disperse through the hydrosystem undetected during winter when PIT-tag monitors are not operating, or pass downstream undetected through a combination of winter passage as well as spring passage when spring spill is implemented. This assumption is largely met when fall Chinook salmon exhibit an ocean-type life history (Healy 1991) characterized by first-year wintering in seawater.

However, some fall Chinook salmon in the Snake River basin exhibit a reservoir-type juvenile life history characterized by first year wintering in reservoirs (Connor et al. 2005). Undetected winter passage in the hydrosystem by reservoir-type juveniles has been documented, and undetected spring passage during spill is possible (Tiffan et al. 2005). Consequently, the Sandford and Smith (2002) approach to calculating SARs may not be suitable for all segments of the Snake River Basin fall Chinook salmon population (Buchanan and Skalski 2006).

Connor et al. (2005) concluded the reservoir-type juvenile life history was important to production of fall Chinook salmon in the Snake River Basin. They found an overall average of 41% of the wild adults studied had wintered in fresh water, according to scale pattern analysis. Scale pattern analysis, however, could not discriminate between adults that had spent their first winter in a reservoir and those that spent their first winter in fresh or estuarine water below Bonneville Dam. Therefore, the conclusion of Connor et al. (2005) relied on an assumption that has since been questioned; that among their study fish, no adult fall Chinook transported as a juvenile had wintered in fresh or estuarine waters downstream from Bonneville Dam.

We began a study in 2005 to document the downstream passage histories of returning PIT-tagged Snake River fall Chinook salmon adults, in part to further understand the juvenile life history strategies of PIT-tagged fish that were never detected during their juvenile migration.

This report has three main objectives. The first was to describe the downstream passage histories of juvenile fall Chinook salmon that returned as adults to Lower Granite Dam from 1998 to 2005. We categorized downstream passage histories based on migration pathway (summer transport, fall transport, or inriver migrant), age at ocean entry (subyearling or yearling), and first-year wintering locale (seawater, reservoir, fresh/estuarine water below Bonneville Dam, or unknown).

Our second objective was to evaluate the effect of age at ocean entry (i.e., subyearling or yearling) on time spent in seawater prior to return to fresh water as an adult. Finally, our third objective was to evaluate the effect of age at ocean entry on fork length of returning adult fall Chinook salmon. It should be noted that to date, sample sizes of fish for these analyses are small and do not fully represent all components and seawater age classes that make up the general population of Snake River basin fall Chinook salmon subyearlings. Accumulation of samples representing this general population is the long-term goal of this study.

METHODS

From September through November 1998-2005, wild and hatchery fall Chinook salmon were collected in the adult trap at Lower Granite Dam (Harmon 2003) as they returned to spawn. Two groups of study fish were collected. The first group was collected from 1998 to 2004. These fish were from life history and juvenile survival studies conducted with PIT-tagged wild and hatchery subyearlings during 1994-1998 and 2000-2002 (e.g., Connor et al. 2002; Smith et al. 2003). If collected at dams downstream from the point of release, these fish had been routed back to the river to continue migration in the river.

The second group of study fish was collected returning to Lower Granite Dam in 2005 primarily from releases of PIT tagged subyearlings made during 2001-2004 transportation studies (e.g., Marsh et al. 2003, 2004a,b, 2005). A portion of these fish were transported for release downstream from Bonneville Dam, while their cohorts were released to complete the juvenile migration in-river. We report results separately for the returns from the life history/juvenile survival and transportation studies. Additional juvenile release and migration data on fish from both studies are provided in the appendix.

Each year, all PIT tag codes of subyearlings tagged for research during the four preceding years were entered into the PIT-tag separation-by-code diversion system (Marsh et al. 1999; Downing et al. 2001) in the adult trap at Lower Granite Dam. We collected scales from each PIT-tagged adult fall Chinook salmon recaptured in the trap. An envelope containing the scale was marked with a sequential sample number, and the sample number and PIT-tag code were then recorded along with gender and fork length.

Scales were analyzed by John Sneva of the Washington Department of Fish and Wildlife to determine origin (wild or hatchery) and whether the first annulus was formed in seawater (seawater annulus) or in fresh water (freshwater annulus; see Connor et al. 2005). A seawater annulus indicated first-year wintering in seawater and age-0 ocean entry, whereas a freshwater annulus indicated first-year wintering in fresh or estuarine water and age-1 ocean entry.

We determined year of ocean entry from age at ocean entry. For example, if a juvenile was released in 1998 and entered seawater as a subyearling, then year of ocean entry was 1998. Scale pattern analysis prior to 2005 preceded the compilation of juvenile PIT-tag histories and was conducted without the knowledge of gender or fork length to ensure blind analysis of scale patterns. In all, 111 scales from fall Chinook adults were collected prior to 2005 and read. No age or origin classification errors were found.

In 2005, scale pattern analysis was incorporated as part of large-scale trapping and brood stock collection for Lyons Ferry Hatchery and the Nez Perce Tribal Hatchery. The data we report for 2005 was error checked by staff of Washington Department of Fish and Wildlife before it was provided to us. We are presently working with Washington Department of Fish and Wildlife and the technical staff of the fall Chinook salmon production committee of U.S. vs. Oregon to develop a long-term program for validating scale pattern analysis.

All fall Chinook included in the life history/juvenile survival group completed their juvenile migration in-river. For transportation study fish, one of three migration pathways was possible; summer transport (21 Jun-31 Aug), fall transport (1 Sep-13 Dec), or inriver migration. For these fish, we used PIT-tag detection histories to determine the juvenile migration pathway of each adult. Transportation was confirmed based on a PIT-tag detection prior to entering a transport holding raceway. Inriver migration was confirmed by either a detection in flumes that routed juveniles back to the river at dams (i.e., fish passed the dam via the juvenile bypass system), or by the absence of a juvenile PIT-tag detection (i.e., fish passed the dam via turbines or spillways).

We were able to conclusively identify first year wintering locale of some of the returning fall Chinook salmon recaptured at the adult trap based on the results of scale pattern analysis and juvenile PIT-tag detection histories. If the scale had a saltwater annulus, then the returning fall Chinook salmon had spent its first winter in saltwater. If the scale had a freshwater annulus, and the juvenile PIT-tag detection history included tagging in year t and detection at a dam in year $t + 1$, then the returning fall Chinook salmon had spent its first winter as a juvenile in a reservoir.

A returning fall Chinook salmon that had spent its first winter as a juvenile in fresh or estuarine water downstream of Bonneville Dam also had scales with freshwater annuli, but conclusive identification of this first-year wintering history required a detection either 1) when the fish was routed to a raceway and transported as a subyearling, or 2) when the fish passed Bonneville Dam via the juvenile fish bypass system as a subyearling. It was impossible to conclusively determine first year wintering locale for a returning fall Chinook salmon that possessed scales with freshwater annuli, but was 1) last detected upstream from Bonneville Dam as a subyearling or 2) never detected as a subyearling or as a yearling.

We calculated time spent in seawater for each returning fall Chinook salmon by subtracting the year of ocean entry from the return year. For example, a subyearling that was released in 1998, entered seawater in 1998, and returned to fresh water in 1999 was classed as a I-salt (Chinook salmon with this life history are males called jacks). A subyearling that was released in 1998, entered seawater as a yearling in 1999, and returned in 2000 would also be a I-salt (and also a jack). Fall Chinook salmon males that enter seawater as yearlings may also return to fresh water as "mini-jacks" after residing at sea for only a few months (Zimmerman et al. 2003). These fish mature and return to spawn in the same year that they enter seawater. We considered only II-salt and III-salt adults to be "full-term" adults.

We pooled results for fall Chinook salmon from the Snake and Clearwater rivers to increase sample sizes for analysis of percentages by seawater class (I-, II-, or III-salt). All percentages were rounded to whole numbers, so percentages summed across individual seawater classes did not always equal 100%.

In most instances, fork length (cm) was measured on adult fish recaptured at the adult trap. To evaluate the effect of age at ocean entry on size at return, we calculated mean fork length by time in seawater. For this analysis, we pooled the data for hatchery fall Chinook salmon from the Snake and Clearwater Rivers across all return years to increase sample sizes. In some instances, gender was assigned to adult fish recaptured at the trap. We calculated mean fork length by age at ocean entry and gender for comparison.

RESULTS

Returns from Juvenile Life History and Survival Studies

Snake River Fall Chinook Salmon

A combined total of 87 returning Snake River fall Chinook salmon (wild n = 12; hatchery n = 75) tagged as subyearlings during juvenile life history and survival studies were recaptured at Lower Granite Dam during 1998-2004 (Table 1). Data collected on 9 returning fish tagged as subyearlings in 1999 are not presented in Table 1 because PIT-tag monitors at the dams were changed to detect a new tag frequency late in 1999. This reduced the number of juvenile migrants detected in fall 1999 and prohibited detection of reservoir-type juvenile migrants in spring 2000.

Within each year, fewer returning adults had entered the ocean as subyearlings than as yearlings (Table 1). Across years, 21.8% of returning adults had entered the ocean as subyearlings and 78.2% had entered as yearlings. The percentage of fish that spent their first winter as juveniles in seawater, reservoirs, or unknown freshwater/estuarine locales varied by year. These percentages calculated across years were 21.8% seawater, 16.7% reservoir, and 61.5% unknown freshwater locale.

Subyearlings from the Snake River that spent their first winter in seawater were usually detected for the last time in summer (Table 1). Subyearling migrants from the Snake River that spent their first winter in seawater passed downstream undetected less frequently (24%; 4 of 17) than Snake River fish that spent their first winter in unknown freshwater locales (48%; 23 of 48).

Age at ocean entry could only be confirmed with absolute certainty for returning fish that were known to be reservoir-type juveniles based on PIT-tag detection. The scales of all 13 Snake River adults that had been identified as reservoir-type juveniles based on PIT-tag detections had freshwater annuli. This validated that the ages at ocean entry assigned by the scale reader were correct.

Table 1. Age at ocean entry and first-year wintering location for fall Chinook salmon PIT-tagged and released into the Snake River as subyearlings during 1994-1998 and 2000-2002 (wild n = 7; hatchery n = 71) from juvenile life history/survival studies. All fish migrated in-river to the tailrace of Bonneville Dam and were recaptured at Lower Granite Dam when returning to spawn during 1998-2004. Last juvenile detection periods were summer (21 Jun-31 Aug), fall (1 Sep-10 Dec), and spring (year t + 1). ND fish were never detected at a dam as a juvenile.

Return year	Age at ocean entry	First-year wintering location	Return year composition N	Return year composition (%)	Last juvenile detection: Summer n (%)	Fall n (%)	Spring n (%)	ND n (%)
1998	Age-0	Seawater	2	(18)	2 (100)	0 (0)		0 (0)
	Age-1	Reservoir	1	(9)			1 (100)	
	Age-1	Unknown	8	(73)	0 (0)	4 (50)		4 (50)
1999	Age-0	Seawater	5	(18)	3 (60)	1 (20)		1 (20)
	Age-1	Reservoir	1	(4)			1 (100)	
	Age-1	Unknown	22	(79)	3 (14)	11 (50)		8 (36)
2000	Age-0	Seawater	8	(36)	6 (75)	0 (0)		2 (25)
	Age-1	Reservoir	6	(27)			6 (100)	
	Age-1	Unknown	8	(36)	2 (25)	3 (38)		3 (38)
2001	Age-0	Seawater	1	(33)	1 (100)	0 (0)		0 (0)
	Age-1	Reservoir	2	(67)			2 (100)	
2002	Age-1	Unknown	1	(100)	0 (0)	0 (0)		1 (100)
2003	Age-1	Reservoir	2	(40)			2 (100)	
	Age-1	Unknown	3	(60)	1 (33)	0 (0)		2 (67)
2004	Age-0	Seawater	1	(13)	0 (0)	0 (0)		1 (100)
	Age-1	Reservoir	1	(13)			1 (100)	
	Age-1	Unknown	6	(75)	1 (17)	0 (0)		5 (83)
1998-2004	Age-0	Seawater	17	(22)	12 (71)	1 (6)		4 (24)
	Age-1	Reservoir	13	(17)			13 (100)	
	Age-1	Unknown	48	(62)	7 (15)	18 (38)		23 (48)

Clearwater River Fall Chinook Salmon

A total of 24 hatchery fall Chinook salmon from the Clearwater River PIT tagged as part of juvenile life history and survival studies were recaptured as adults at Lower Granite Dam during 1999-2004 (Table 2). Data collected on 12 of these fish, which were tagged as subyearlings in 1999, are not presented in Table 2 because of the change in frequency of PIT-tag detectors (as described above for Snake River fish). Of the remaining 12 fish analyzed, 16.7% (*n* = 2) had entered the ocean as subyearlings and 83.3% (*n* = 10) had entered as yearlings (Table 2). First-year wintering location percentages calculated across years were 16.7% seawater, 41.7% reservoir, and 41.7% unknown freshwater/estuary locale.

Table 2. Age at ocean entry and first-year wintering location for hatchery fall Chinook salmon (*n* = 12) PIT-tagged and released into the Clearwater River as subyearlings during 1996-1998 and 2000-2002 as part of juvenile life history/survival studies. These fish migrated in-river to the tailrace of Bonneville Dam as juveniles and were recaptured at Lower Granite Dam when returning to spawn during 1999-2004. Last juvenile detections in all years were summer (21 Jun-31 Aug), fall (1 Sep-10 Dec), and spring (year *t* + 1). NDs were fish never detected at a dam as a juvenile.

			Return year composition		Last juvenile detection			
		First-year			Summer	Fall	Spring	ND
Return year	Age at ocean entry	wintering location	*N*	(%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)
1998-2004	Age-0	Seawater	2	(17)	2 (100)			
	Age-1	Reservoir	5	(42)			5 (100)	
	Age-1	Unknown	5	(42)	1 (20)	1 (20)		3 (60)

Two Clearwater River fish spent their first winter in seawater and were last detected in summer. Of the 5 inriver migrants from the Clearwater River that spent their first winter in unknown freshwater/estuarine locales, 3 passed downstream undetected, 1 was last detected in summer, and 1 was last detected in fall.

The scales of all 5 returning fall Chinook salmon from the Clearwater River that had been determined by PIT-tag detection to be reservoir-type juveniles had freshwater annuli. This again validated that correct ages at ocean entry were assigned by the scale reader.

Time in Seawater for Snake and Clearwater River Fall Chinook Salmon

For adult fall Chinook salmon that had been PIT tagged as part of juvenile life history and survival studies in the Snake and Clearwater rivers combined, time spent in seawater ranged from 1 to 3 years for subyearling ocean entrants and from less than 1 year to 3 years for yearling ocean entrants (Table 3). Subyearling ocean entrants did not return as mini-jacks, and they were less likely than yearling ocean entrants to return as jacks (Table 3). Eighty-eight percent of the fish with a subyearling scale pattern returned as full-term adults, whereas only 67% of the fish with a yearling scale pattern returned as full-term adults. Of the 81 full-term adults (II- and III-salts), 34.6% entered the ocean as subyearlings and 65.4% as yearlings.

Table 3. Number of years spent in seawater by fall Chinook salmon (wild n = 12; hatchery n = 99) PIT tagged as subyearlings in the Snake and Clearwater Rivers during 1994-1998 and 2000-2002 as part of juvenile life history/survival studies. These fish migrated in-river to the tailrace of Bonneville Dam, entered the ocean as subyearlings or yearlings, and were then recaptured at Lower Granite Dam when returning to spawn during 1998-2005. Mini-jacks did not spend a full year in seawater, and only II- and III-salts were considered full-term adults.

		Mini-jacks	I-salt	II-salt	III-salt
Age at ocean entry	*N*	*n* (%)	*n* (%)	*n* (%)	*n* (%)
Age-0	32	0 (0)	4 (13)	15 (47)	13 (41)
Age-1	79	8 (10)	18 (23)	25 (32)	28 (35)

Size at Return for Snake and Clearwater River Fall Chinook Salmon

For fish released as part of juvenile life history and survival studies in the Snake and Clearwater Rivers combined, mean fork length at return increased with time spent in seawater (Figure 2). Within each seawater class, returning fall Chinook salmon that had entered the ocean as subyearlings were smaller as adults than those that had entered the ocean as yearlings (Figure 2). Full-term female adults that had entered the ocean as subyearlings averaged 75 $\pm$ 10 cm (SD; n = 10) compared to full-term female adults that had entered the ocean as yearlings at 79 $\pm$ 7 cm (SD; n = 27). Full-term male adults that had entered the ocean as subyearlings averaged 73 $\pm$ 14 cm (SD; n = 10) compared to full-term male adults that had entered the ocean as yearlings at 82 $\pm$ 16 cm (SD; n = 13).

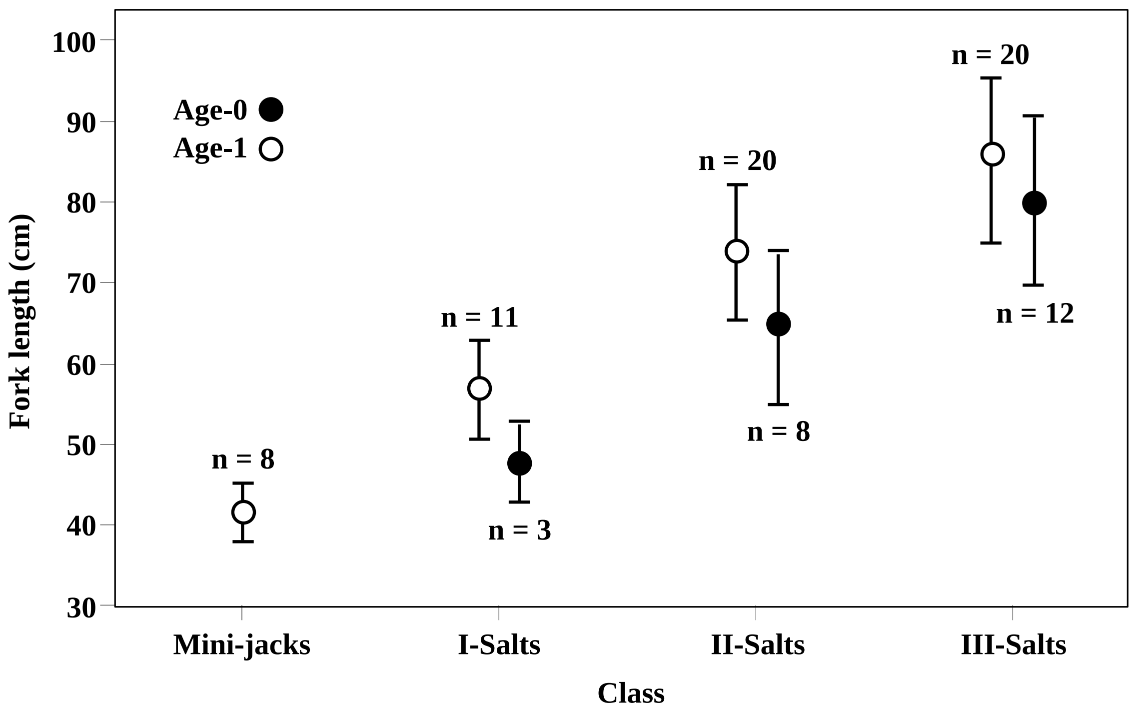

Figure 2. Mean fork length (cm) of fall Chinook salmon (wild n = 8; hatchery n = 74) that had been PIT tagged as subyearlings during 1994-1998 and 2000-2002 in the Snake and Clearwater Rivers as part of juvenile life history/survival studies. These fish migrated to the tailrace of Bonneville Dam, entered the ocean as subyearlings (age-0, black circle) or yearlings (age-1, open circle), and were recaptured and measured at Lower Granite Dam when returning to spawn during 1998-2005. Mini-jacks did not spend a full year in seawater, and only II- and III-salts were considered full-term adults.

Returns from 2001-2004 Transportation Study Releases

Transported Fall Chinook Salmon

During 2005, we collected scale samples at Lower Granite Dam from 53 adult Chinook salmon that had been PIT tagged as subyearlings during 2001-2004, transported, and released below Bonneville Dam. Of the 20 recaptured adults transported as juveniles during summer, 65% had entered the ocean as subyearlings and 35% as yearlings; yearling ocean entrants wintered in fresh or estuarine water downstream from Bonneville Dam (Table 4). Of the 33 remaining adults that had been transported as juveniles during fall, 39% had entered the ocean as subyearlings and 61% as yearlings after wintering in fresh or estuarine water downstream from Bonneville Dam.

Inriver Migrant Fall Chinook Salmon

A total of 28 returning PIT-tagged adults from transportation studies had migrated in-river as juveniles (Table 4). Yearling ocean entrants that had wintered in unknown freshwater/estuarine locales were predominant, making up 46.4% of the adults. First-year wintering location percentages calculated across years were 21.4% seawater, 32.1% reservoir, and 46.4% unknown freshwater/estuarine locale.

Inriver migrants that spent their first winter in seawater were usually detected for the last time in summer (Table 4). None of the 6 inriver migrants that spent their first winter in seawater passed downstream undetected. Of the 13 inriver migrants that spent their first winter in unknown freshwater/estuarine locales, 10 passed downstream undetected, 1 was detected in summer, and 2 were detected in fall.

Time in Seawater for Transported and Inriver Fish

For fall Chinook from all migrational pathways combined, time spent in seawater ranged from 1 to 3 years for fish that entered the ocean as subyearlings and from less than 1 year to 3 years for fish that entered as yearlings (Table 5). Subyearling ocean entrants did not return as mini-jacks, but otherwise, jack returns were similar between subyearling and yearling ocean entrants (Table 5). Further, 75% of the fish with a subyearling scale pattern returned as full term adults, whereas only 63% of the fish with a yearling scale pattern returned as full term adults. Of the 55 full-term adults (II- and III-salts), 44% entered the ocean as subyearlings and 56% as yearlings.

Table 4. Migration pathway, age at ocean entry, and first-year wintering location for fall Chinook salmon (wild n = 11; hatchery n = 57; unconfirmed n = 13) that were PIT-tagged during transportation studies and released into the Snake River as subyearlings during 2001-2004. Fish were recaptured at Lower Granite Dam when returning to spawn in 2005. Last juvenile detections for all years were summer (21 Jun-31 Aug), fall (1 Sep-10 Dec), and spring (year t + 1). ND fish were never detected at a dam as a juvenile (non-detected inriver group); Below BON = fresh water/estuary downstream from Bonneville Dam.

Migration pathway	Age at ocean entry	First-year wintering location	Intra-pathway composition *N*	(%)	Last juvenile detection: Summer n (%)	Fall n (%)	Spring n (%)	ND n (%)
Summer transport	Age-0	Seawater	13	(65)	13 (100)			
	Age-1	Below BON	7	(35)	7 (100)			
Fall transport	Age-0	Seawater	13	(39)	13 (100)			
	Age-1	Below BON	20	(61)	20 (100)			
Inriver	Age-0	Seawater	6	(21)	5 (83)	1 (17)		0 (0)
	Age-1	Reservoir	9	(32)			9 (100)	
	Age-1	Unknown	13	(46)	1 (8)	2 (15)		10 (77)

Table 5. Number of years spent in seawater by fall Chinook salmon (wild n = 11; hatchery n = 57; unconfirmed n = 13) PIT-tagged during 2001-2004 for transportation studies. Fish entered the ocean as subyearlings (age-0) or yearlings (age-1), and were recaptured at Lower Granite Dam when returning to spawn in 2005. Data is for spring- and summer-transported fish and inriver migrants combined. Mini-jacks did not spend a full year in seawater, and only II-salts and III-salts were considered full-term adults.

Age at ocean entry	*N*	Mini-jacks *n* (%)	I-salt *N* (%)	II-salt *n* (%)	III-salt *n* (%)
Age-0	32	0 (0)	8 (25)	13 (41)	11 (34)
Age-1	49	8 (16)	10 (20)	28 (57)	3 (6)

Size at Return for Transported and Inriver Fish

For analysis of size at return, data were pooled for transported and inriver migrant fall Chinook salmon. Mean fork length at return increased with time spent in seawater (Figure 3). Within each seawater class, adult fall Chinook salmon that had entered the ocean as subyearlings were smaller than those that had entered the ocean as yearlings (Figure 3). Full-term female adults that had entered the ocean as subyearlings averaged 75 $\pm$ 3 cm (SD; n = 6) compared to full-term female adults that had entered the ocean as yearlings at 74 $\pm$ 7 cm (SD; n = 20). Full-term male adults that had entered the ocean as subyearlings averaged 69 $\pm$ 5 cm (SD; n = 18) compared to full-term male adults that had entered the ocean as yearlings at 70 $\pm$ 9 cm (SD; n = 11). Sex was not determined for all returning adults.

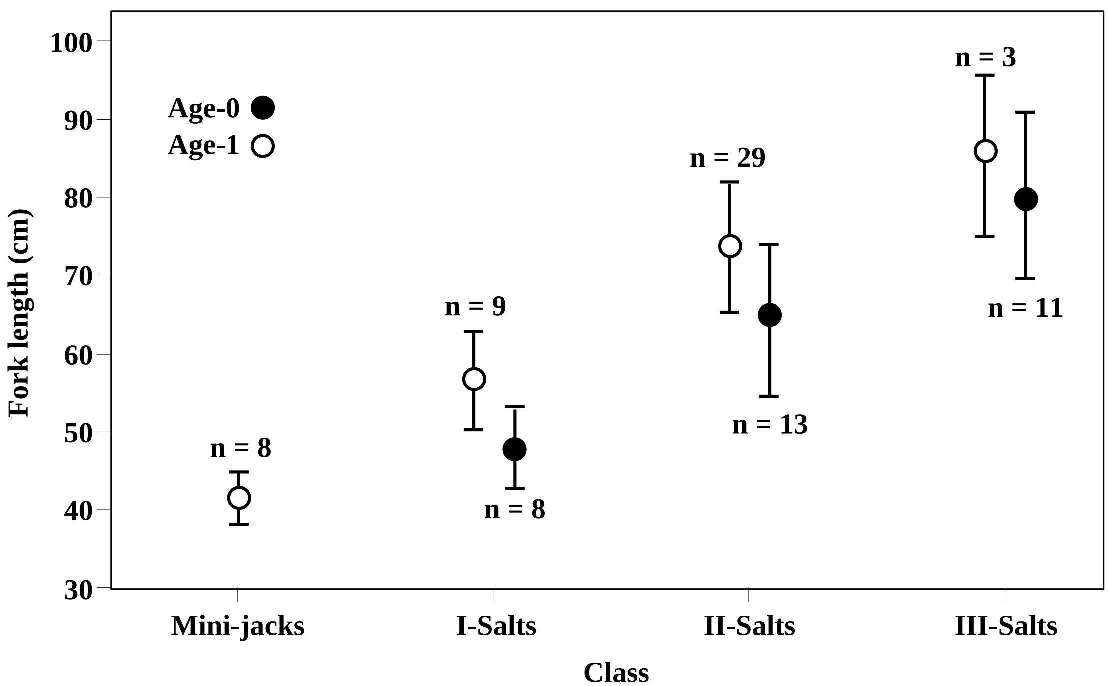

Figure 3. Mean fork length (cm) of fall Chinook salmon (wild n = 11; hatchery n = 57; unconfirmed n = 13) that were PIT-tagged during 2001-2004 transportation studies. Fish were either transported or migrated in-river, entered the ocean as subyearlings (age-0, black circles) or yearlings (age-1, open circles), and were then recaptured and measured at Lower Granite Dam when returning to spawn in 2005. Mini-jacks did not spend a full year in seawater and only II- and III-salts were considered full-term adults.

DISCUSSION

As we have emphasized throughout this report, sample sizes for this study are presently limited. Therefore, our analyses pooled data among all components, seawater age classes, and genders making up the Snake River basin population of fall Chinook salmon subyearlings. When sample sizes increase in future years, analyses that will more fully represent the population will be feasible. Acknowledging this limitation, we focus our discussion on broad overall trends.

We analyzed data on a total of 118 returning fall Chinook salmon recaptured at Lower Granite Dam during 1998-2005 that had been tagged as subyearlings and released to migrate in-river as part of juvenile life history/survival and transportation studies during 1994-1998 and 2000-2002. Of these adults, 93 (79%) had entered the ocean as yearlings. Of these 93 yearling ocean entrants, 27 were known to have spent their first winter in reservoirs and the remaining 66 in unknown freshwater/estuarine locales. Two lines of evidence suggest that many of the 66 yearling ocean entrants likely wintered in reservoirs upstream from Bonneville Dam.

First, of these 66 fish, 30 had been detected upstream from Bonneville Dam, with 21 of these detections occurring in fall. Because migrational disposition decreases as the season progresses (Connor et al. 2003a), it is unlikely that many fish detected upstream from Bonneville Dam in fall subsequently passed all remaining dams, including Bonneville, before winter. The second line of evidence applies to the remaining 36 yearling ocean entrants that were never detected as juveniles. Summer spill was very limited at Snake River dams during the years when these subyearlings were released. When spill was not fully implemented at these dams, the estimated probability of an actively migrating PIT-tagged subyearling to survive passage from Lower Granite Reservoir to the tailrace of Lower Monumental Dam without detection was 7% or less (Appendix Table C). Though data are not available to estimate this probability for the entire river from Lower Granite Reservoir to Bonneville Dam tailrace, it would be lower than 7% because additional detections would likely occur at McNary, John Day, and Bonneville Dam.

In the instance of reservoir-type juveniles, undetected passage was possible, and documented during the years studied, because the juvenile fish bypass systems were not operated during the winter, and spring spill was implemented at Columbia River dams when those yearlings remaining in the hydrosystem migrated (Tiffan and Connor 2005). Therefore, we concluded that a large portion of the yearlings that overwintered in unknown locales were reservoir-type juveniles.

For fall Chinook salmon tagged for transportation studies, adults that returned to Lower Granite Dam in 2005 after being transported as subyearlings had entered the ocean as both subyearlings and yearlings. This finding confirmed that transported subyearlings do winter in fresh or estuarine waters below Bonneville Dam. Though we expected to see this in some transported subyearlings, the actual number observed was much larger than expected, especially in the fall transport group.

The difference in patterns of age at ocean entry between fish that were transported in summer vs. fall was consistent with a seasonal decrease in migrational disposition. Fish transported in summer were mostly active ocean-type juveniles that continued seaward movement after transportation. Conversely, fish transported in fall may have been collected at a dam when making short-term downstream excursions to eventual wintering locations. This juvenile life-history strategy has been observed for subyearling spring Chinook salmon produced in headwater streams (e.g., Chapman and Bjornn 1969; Bjornn 1971).

We found that for fall Chinook salmon returning from releases made during juvenile life history/survival and transportation studies, time spent in seawater was dependent on age at ocean entry. Subyearling ocean entrants were less likely to return after spending a year or less at sea than yearling ocean entrants. Yearling ocean entrants produced more jacks and mini-jacks than subyearling ocean entrants; however, they still made up the majority of full-term adults recaptured at Lower Granite Dam.

Equally as important, we found that full-term adults that had entered the ocean as yearlings were similar or larger in fork length than those adults that had entered the ocean as subyearlings. This finding provides a different perspective on the effects of juvenile life history than that of previous size comparisons by total age (i.e., return year minus brood year; e.g., Connor et al. 2005; Milks et al. 2006). Analyses conducted on total age are inadequate in that they fail to capture the fact that yearling ocean entry does not result in a reduction of body size of full-term adults. Moreover, body size, not age, is the factor that most influences stock productivity.

It is clear that fall Chinook salmon juveniles from the Snake River basin employ diverse downstream passage strategies to reach the sea. These strategies need to be considered when designing hydrosystem survival studies and planning recovery measures. Our results show that the assumption of Connor et al. (2005), that no transported juveniles winter in fresh or estuarine water below Bonneville Dam, is not valid. However, they support the idea that wintering in reservoirs and entering the ocean as yearlings is a productive downstream passage strategy for Snake River Basin fall Chinook salmon.

Our findings also underscore the importance of understanding the migration history of all returning adults and the difficulty in attempting to make unbiased SAR estimates for non-detected inriver migrant groups. The fall Chinook salmon adults we recaptured began inriver migration as subyearlings during 1994-2004, when summer spill was not routinely implemented at Lower Granite, Little Goose, or Lower Monumental dams. Therefore, results for these fish provide a baseline of data from non-summer spill years for comparison with future results from years with summer spill. We plan to recapture and sample scales from additional PIT-tagged adults returning to Lower Granite Dam from releases in 2003 and 2004 to expand this baseline.

Further, large releases of PIT-tagged fall Chinook salmon subyearlings were made in 2005 and 2006, when summer spill was fully implemented at all four lower Snake River dams. We have proposed to recapture and sample scales from adults returning from these releases as well. This will allow the first comparison of adult returns from both spill and non-spill years, and will help determine whether spill alters the numbers of fish in the non-detected inriver group that migrate as yearlings.

A detailed study of the migrational behavior and prevalence of reservoir-type juveniles began in 2003 and will continue through 2009 (Tiffan and Connor 2005). Determining the prevalence of inriver migrants that winter in fresh or estuarine waters downstream from Bonneville Dam is another important area of future research. This could be accomplished with PIT-tags, radio transmitters, acoustic transmitters, or a detection array below Bonneville Dam.

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REFERENCES

Buchanan, R. A. and J. R. Skalski. 2006. Design and analysis of salmonid tagging studies in the Columbia Basin, volume XIX. Report of the University of Washington School of Aquatic and Fishery Sciences to the Bonneville Power Administration, Portland, Oregon.

Bjornn, T. C. 1971. Trout and salmon movement in two streams as related to temperature, food, stream flow, cover, and population density. Transactions of the American Fisheries Society 100:423-438.

Chapman, D. W., and T. C. Bjornn. 1969. Distribution of salmonids in streams with special reference to food and feeding. Pages 153-176 *in* T. G. Northcote, editor. Symposium on salmon and trout streams. University of British Columbia, Vancouver.

Connor, W. P., H. L. Burge, R. Waitt, and T. C. Bjornn. 2002. Juvenile life history of wild fall Chinook salmon in the Snake and Clearwater rivers. North American Journal of Fisheries Management 22:703-712.

Connor, W. P., J. G. Sneva, K. F. Tiffan, R. K. Steinhorst, D. Ross. 2005. Two alternative juvenile life histories for fall Chinook salmon in the Snake River basin. Transactions of the American Fisheries Society 134:291-304.

Connor, W. P., R. K. Steinhorst, and H. L. Burge. 2003a. Migrational behavior and seaward movement of wild subyearling fall Chinook salmon in the Snake River. North American Journal of Fisheries Management 23:414-430.

Connor, W. P., H. L. Burge, J. R. Yearsley, and T. C. Bjornn. 2003b. The influence of flow and temperature on survival of wild subyearling fall Chinook salmon in the Snake River. North American Journal of Fisheries Management 23:362-375.

Cormack, R. M. 1964. Estimates of survival from the sighting of marked animals. Biometrika 51:429–438.

Downing, S. L., E. F. Prentice, R. W. Frazier, J. E. Simonson, E. P. Nunnallee. 2001. Technology developed for diverting passive integrated transponder (PIT) tagged fish at hydroelectric dams in the Columbia River Basin. Aquacultural Engineering, 25:149-164.

Harmon, J. R. 2003. A trap for handling adult anadromous salmonids at Lower Granite Dam on the Snake River, Washington. North American Journal of Fisheries Management 23:989-992.

Healey, M. C. 1991. Life history of Chinook salmon (*Oncorhynchus tshawytscha*). Pages 312 to 393 *in* C. Groot and L. Margolis, editors, Pacific salmon life histories. UBC press, Vancouver, British Columbia.

Jolly, G. M. 1965. Explicit estimates from capture-recapture data with both death and immigration - stochastic model. Biometrika 52:225–247.

Marsh, D. M., J. R. Harmon, N. N. Paasch, K. L. Thomas, K. W. McIntyre, B. P. Sandford, and G. M. Matthews. 2004a. Transportation of juvenile salmonids on the Columbia and Snake Rivers, 2003: final report for 2000 and 2001 steelhead juveniles. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Marsh, D. M., J. R. Harmon, N. N. Paasch, K. L. Thomas, K. W. McIntyre, B. P. Sandford, and G. M. Matthews. 2004b. Research related to transportation of juvenile salmonids on the Columbia and Snake Rivers, 2002. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Marsh, D. M., J. R. Harmon, N. N. Paasch, K. L. Thomas, K. W. McIntyre, B. P. Sandford, and G. M. Matthews. 2003. Research related to transportation of juvenile salmonids on the Columbia and Snake Rivers, 2001. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Marsh, D. M., J. R. Harmon, N. N. Paasch, K. L. Thomas, K. W. McIntyre, B. P. Sandford, G. M. Matthews, and W. D. Muir. 2005. Transportation of juvenile salmonids on the Columbia and Snake Rivers, 2004: final report for 2002 steelhead juveniles. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Marsh, D. M., G. M. Matthews, S. Achord, T. E. Ruehle, and B. P. Sandford. 1999. Diversion of salmonid smolts tagged with passive integrated transponders from an untagged population passing through a juvenile collection system. North American Journal of Fisheries Management 19:1142-1146.

Milks, D., M. Varney, J. Jording, and M. Schuck. 2006. Lyons Ferry Hatchery evaluation fall Chinook salmon. 2003 and 2004 annual report to the U. S. Fish and Wildlife Service Lower Snake River Compensation Plan Office, Boise, Idaho.

Prentice, E. F., T. A. Flagg, and C. S. McCutcheon. 1990a. Feasibility of using implantable passive integrated transponder (PIT) tags in salmonids. American Fisheries Society Symposium 7:317-322.

Prentice, E. F., T. A. Flagg, C. S. McCutcheon, and D. F. Brastow. 1990b. PIT-tag monitoring systems for hydroelectric dams and fish hatcheries. American Fisheries Society Symposium 7:323-334.

Sandford, B. P., and S. G. Smith. 2002. Estimation of smolt-to-adult return percentages for Snake River Basin anadromous salmonids, 1990-1997. Journal of Agricultural Biological, and Environmental Statistics 7:243-263.

Seber, G. A. F. 1965. A note on the multiple recapture census. Biometrika 52:249-259.

Smith, S. G., W. D. Muir, E. E. Hockersmith, R.W. Zabel, R. J. Graves, C. V. Ross, W. P. Connor, and B. D. Arnsberg. 2003. Influence of river conditions on survival and travel time of Snake River subyearling fall Chinook salmon. North American Journal of Fisheries Management 23: 939-961.

Tiffan, K. F., and W. P. Connor. 2005. Investigating passage of ESA-listed juvenile fall Chinook salmon at Lower Granite Dam during winter when the fish bypass system is not operated. 2004 Annual report to the Bonneville Power Administration for project 200203200.

Zimmerman, C. E., R. W. Stonecypher, Jr., and M. C. Hayes. 2003. Migration o precocious male hatchery Chinook salmon in the Umatilla River, Oregon. North American Journal of Fisheries Management 23:1006-1014.

APPENDIX: Data Tables for Study Fish

Appendix Table A. Data collected on adult fall Chinook salmon PIT tagged as subyearlings as part of juvenile life history/survival research and recaptured as adults at Lower Granite Dam. All fish were released after tagging to migrate in-river. Abbreviations not common to PIT-tag data: SNK RAL, Snake River run at large; AOE, age at ocean entry; OA, ocean age or seawater class; FL, fork length of adults (cm).

Group	Migration year	Release site	Last detection dam	Last detection date	Return year	Origin	Age at ocean entry	Ocean age	Gender	FL (mm)
SNK RAL	1994	SNAKER	LMJ	04/03/1995	1998	W	1	3	F	83
SNK RAL	1995	SNAKER	ND	.	1998	W	1	2	F	80
SNK RAL	1995	SNAKER	ND	.	1999	W	1	3	M	102
SNK RAL	1995	SNAKER	MCJ	12/06/1995	1999	W	1	3	M	72
SNK RAL	1997	SNAKER	GOJ	09/18/1997	2000	W	1	2	M	67
SNK RAL	1997	SNAKER	BON	04/30/1998	2000	W	1	2	F	87
SNK RAL	1998	SNAKER	GOJ	09/16/1998	2000	W	1	1	M	61
SNK RAL	1999	SNAKER	MCJ	09/18/1999	2001	W	0	2	.	.
SNK RAL	1999	SNAKER	JDJ	07/27/1999	2002	W	0	3	M	80
SNK RAL	1999	SNAKER	GOJ	08/08/1999	2001	W	0	2	.	.
SNK RAL	1999	SNAKER	GRJ	07/21/1999	2001	W	0	2	.	.
SNK RAL	1999	SNAKER	GRJ	08/05/1999	2001	W	0	2	.	.
Surrogates	1995	SNAKER	ND	.	1998	H	1	2	F	74
Surrogates	1995	SNAKER	ND	.	1998	H	1	2	F	76
Surrogates	1995	SNAKER	GRJ	09/09/1995	1998	H	1	2	F	84
Surrogates	1995	SNAKER	ND	.	1999	H	1	3	M	.
Surrogates	1995	SNAKER	MCJ	12/07/1995	1999	H	1	3	.	.
Surrogates	1995	SNAKER	LMJ	09/23/1995	1999	H	1	3	M	.
Surrogates	1995	SNAKER	LMJ	09/23/1995	1998	H	1	2	F	77
Surrogates	1995	SNAKER	GOJ	09/14/1995	1998	H	1	2	F	72
Surrogates	1995	SNAKER	ND	.	1999	H	1	3	F	84
Surrogates	1995	SNAKER	ND	.	1999	H	1	3	F	.
Surrogates	1995	SNAKER	ND	.	1998	H	1	2	F	78
Surrogates	1995	SNAKER	MCJ	12/10/1995	1999	H	1	3	F	73
Surrogates	1995	SNAKER	GOJ	10/14/1995	1999	H	1	3	F	90
Surrogates	1995	SNAKER	LMJ	08/01/1995	1998	H	0	3	F	81
Surrogates	1995	SNAKER	GOJ	08/12/1995	1999	H	1	3	M	104
Surrogates	1995	SNAKER	LMJ	07/28/1995	1998	H	0	3	F	90
Surrogates	1995	SNAKER	GRJ	10/12/1995	1999	H	1	3	M	99
Surrogates	1995	SNAKER	GRJ	09/19/1995	1999	H	1	3	F	78
Surrogates	1995	SNAKER	ND	.	1999	H	1	3	F	90

Appendix Table A. Continued.

Group	Migration year	Release site	Last detection dam	Last detection date	Return year	Origin	Age at ocean entry	Ocean age	Gender	FL (mm)
Surrogates	1995	SNAKER	GOJ	09/21/1995	1999	H	1	3	M	76
Surrogates	1995	SNAKER	ND	.	1999	H	1	3	F	82
Surrogates	1995	SNAKER	MCJ	11/30/1995	1999	H	1	3	M	.
Surrogates	1995	SNAKER	GOJ	09/01/1995	1999	H	1	3	.	.
Surrogates	1995	SNAKER	ND	.	1999	H	1	3	.	.
Surrogates	1995	SNAKER	LMJ	08/08/1995	1999	H	1	3	M	100
Surrogates	1995	SNAKER	GOJ	09/02/1995	1998	H	1	2	F	70
Surrogates	1995	SNAKER	ND	.	1999	H	1	3	M	77
Surrogates	1996	SNAKER	ND	.	2000	H	1	3	M	82
Surrogates	1996	CLWR	MCJ	12/13/1996	2000	H	1	3	M	87
Surrogates	1996	SNAKER	GOJ	09/29/1996	1999	H	0	3	F	58
Surrogates	1996	CLWR	ND	.	2000	H	1	3	F	87
Surrogates	1996	CLWR	GOJ	08/05/1996	1999	H	0	3	F	76
Surrogates	1996	SNAKER	MCJ	04/05/1997	1999	H	1	2	F	67
Surrogates	1996	CLWR	ND	.	2000	H	1	3	F	81
Surrogates	1996	SNAKER	ND	.	2000	H	1	3	F	78
Surrogates	1996	SNAKER	LMJ	08/03/1996	1999	H	1	2	F	78
Surrogates	1997	SNAKER	LMJ	07/21/1997	1999	H	0	2	F	66
Surrogates	1997	SNAKER	MCJ	04/23/1998	2001	H	1	3	.	.
Surrogates	1997	SNAKER	GRJ	07/10/1997	2000	H	0	3	F	76
Surrogates	1997	SNAKER	MCJ	05/09/1998	2000	H	1	2	F	75
Surrogates	1997	SNAKER	GRJ	07/01/1997	2000	H	1	2	.	75
Surrogates	1997	SNAKER	LMJ	04/13/1998	2000	H	1	2	M	51
Surrogates	1997	SNAKER	ND	.	1999	H	0	2	M	.
Surrogates	1997	CLWR	MCJ	04/23/1998	2000	H	1	2	F	72
Surrogates	1997	SNAKER	GOJ	06/20/1997	1999	H	0	2	F	65
Surrogates	1997	CLWR	ND	.	2000	H	1	2	F	.
Surrogates	1997	SNAKER	LMJ	09/24/1997	1999	H	1	1	F	61
Surrogates	1997	SNAKER	LMJ	07/24/1997	2000	H	0	3	F	77
Surrogates	1998	SNAKER	LMJ	07/24/1998	1999	H	0	1	M	.
Surrogates	1998	CLWR	MCJ	04/21/1999	2000	H	1	1	M	61
Surrogates	1998	SNAKER	ND	.	2002	H	1	3	F	87
Surrogates	1998	CLWR	MCJ	08/01/1998	2000	H	0	2	F	72
Surrogates	1998	SNAKER	GOJ	08/08/1998	2000	H	1	1	M	62
Surrogates	1998	SNAKER	LMJ	08/12/1998	2000	H	1	1	M	62
Surrogates	1998	CLWR	MCJ	05/13/1999	2000	H	1	1	M	57
Surrogates	1999	CLWR	ND	.	2002	H	0	3	M	80
Surrogates	1999	CLWR	ND	.	2000	H	1	0	M	41
Surrogates	1999	CLWR	ND	.	2000	H	0	1	M	44
Surrogates	1999	CLWR	GRJ	08/29/1999	2000	H	1	0	M	41
Surrogates	1999	SNAKER	LMJ	07/26/1999	2001	H	0	2	.	.
Surrogates	1999	CLWR	ND	.	2000	H	1	0	M	47
Surrogates	1999	CLWR	ND	.	2000	H	1	0	M	40

Appendix Table A. Continued.

Group	Migration year	Release site	Last detection dam	Last detection date	Return year	Origin	Age at ocean entry	Ocean age	Gender	FL (mm)
Surrogates	1999	CLWR	LMJ	07/31/1999	2002	H	0	3	M	95
Surrogates	1999	CLWR	ND	.	2000	H	1	0	M	40
Surrogates	1999	SNAKER	ND	.	2000	H	1	0	M	44
Surrogates	1999	CLWR	ND	.	2000	H	1	0	M	39
Surrogates	1999	SNAKER	GRJ	08/29/1999	2001	H	1	1	.	.
Surrogates	2001	SNAKER	ND	.	2004	H	1	2	.	.
Surrogates	2001	SNAKER	JDJ	05/09/2002	2003	H	1	1	M	50
Surrogates	2001	SNAKER	ND	.	2003	H	1	1	M	48
Surrogates	2001	PLAP	GRJ	07/19/2001	2003	H	1	1	M	52
Surrogates	2001	SNAKER	ND	.	2004	H	1	2	.	.
Surrogates	2001	SNAKER	MCJ	04/30/2002	2003	H	1	1	M	50
Surrogates	2002	SNAKE3	JDJ	08/20/2002	2004	H	1	1	.	.
Surrogates	2002	SNAKER	ND	.	2004	H	1	1	.	.
Surrogates	2002	SNAKE3	JDJ	04/18/2003	2004	H	1	1	.	.
Surrogates	2002	SNAKE3	ND	.	2004	H	1	1	.	.
Surrogates	2002	SNAKE3	ND	.	2003	H	1	0	M	41
Surrogates	2002	SNAKE3	ND	.	2004	H	0	2	.	.
Surrogates	2002	SNAKE3	ND	.	2004	H	1	1	.	.
SNK RAL	1999	SNAKER	MCJ	07/07/1999	2000	H	0	1	M	49
Production	1997	SNAKER	LMJ	07/21/1997	2000	H	0	3	M	75
Production	1997	SNAKER	MCJ	04/29/1998	2000	H	1	2	F	66
Production	1997	SNAKER	MCJ	04/30/1998	2000	H	1	2	F	76
Production	1997	SNAKER	ND	.	2000	H	1	2	F	80
Production	1997	SNAKER	GOJ	04/25/1998	2000	H	1	2	M	71
Production	1998	SNAKER	ND	.	2000	H	0	2	M	72
Production	1998	SNAKER	GOJ	06/13/1998	2001	H	0	3	.	.
Production	1998	SNAKER	MCJ	07/08/1998	2000	H	0	2	M	70
Production	1998	SNAKER	MCJ	07/14/1998	2000	H	0	2	M	66
Production	1998	SNAKER	ND	.	2000	H	0	2	M	46
Production	1998	SNAKER	GOJ	07/19/1998	2000	H	0	2	M	60
Production	1998	SNAKER	MCJ	04/27/1999	2001	H	1	2	.	.
Production	1999	CJRAP	MCJ	08/06/1999	2002	H	0	3	F	87
Production	1999	BCCAP	GOJ	07/21/1999	2002	H	0	3	M	87
Production	1999	BCCAP	GOJ	08/01/1999	2000	H	0	1	M	51
Production	2001	BCCAP	JDJ	04/20/2002	2003	H	1	1	F	60
Production	2001	BCCAP	GRJ	08/17/2001	2004	H	1	2	.	.
Production	2002	BCCAP	BON	05/21/2003	2004	H	1	1	.	.

Appendix Table B. Data collected on fall Chinook adults recaptured at Lower Granite Dam that had been PIT tagged as subyearlings as part of transportation research. Abbreviations that are not common to PIT-tag data: LGR RAL, Lower Granite Dam run at large; Trans, transport; Sum, Summer; SNK RAL, Snake River run at large; AOE, age at ocean entry; OA, ocean age or seawater class; FL, fork length of adults (cm).

Migration pathway	Group	Migration year	Release site	Dam	Date	Return year	Origin	AOE	OA	Gender	FL
Fall trans	LGR RAL	2002	LGRRTR	GRJ	10/29/2002	2005	W	1	2	M	79
Fall trans	LGR RAL	2003	LGRRTR	GRJ	09/05/2003	2005	W	0	2	M	63
Fall trans	LGR RAL	2003	LGRRTR	GRJ	10/31/2003	2005	W	1	1	M	62
Fall trans	LGR RAL	2003	LGRRTR	GRJ	09/17/2003	2005	W	1	1	M	55
Fall trans	LGR RAL	2003	LGRRTR	GRJ	10/01/2003	2005	W	0	2	M	63
Fall trans	LGR RAL	2004	LGRRTR	GRJ	10/29/2004	2005	W	1	0	M	49
Fall trans	LGR RAL	2004	LGRRTR	GRJ	10/27/2004	2005	W	1	0	M	36
Fall trans	LGR RAL	2004	LGRRTR	GRJ	09/29/2004	2005	W	0	1	M	45
Fall trans	LGR RAL	2004	LGRRTR	GRJ	09/23/2004	2005	W	0	1	M	46
Inriver	LGR RAL	2004	LGRRRR	GOJ	09/10/2004	2005	W	0	1	M	52
Fall trans	LGR RAL	2004	LGRRTR	GRJ	10/07/2004	2005	W	1	0	M	44
Inriver	Surrogates	2001	SNAKER	ND	.	2005	H	1	3	F	76
Inriver	Surrogates	2001	SNAKER	ND	.	2005	H	1	3	F	77
Inriver	Surrogates	2001	SNAKER	ND	.	2005	H	1	3	F	83
Inriver	Surrogates	2002	SNAKE3	BON	04/30/2003	2005	H	1	2	F	69
Sum trans	Surrogates	2002	SNAKE3	GRJ	07/31/2002	2005	H	0	3	F	76
Sum trans	Surrogates	2002	SNAKE3	GOJ	07/22/2002	2005	H	1	2	F	66
Inriver	Surrogates	2002	SNAKE3	MCJ	04/19/2003	2005	H	1	2	F	76
Inriver	Surrogates	2002	SNAKE3	LMJ	04/26/2003	2005	H	1	2	M	69
Inriver	Surrogates	2002	SNAKE3	GOJ	07/26/2002	2005	H	0	3	F	72
Inriver	Surrogates	2002	SNAKE3	MCJ	04/05/2003	2005	H	1	2	F	55
Fall trans	Surrogates	2002	SNAKE3	GRJ	10/03/2002	2005	H	0	3	F	73
Sum trans	Surrogates	2002	SNAKE3	GRJ	07/29/2002	2005	H	0	3	M	74
Inriver	Surrogates	2002	SNAKE3	GRJ	07/31/2002	2005	U	0	3	M	75
Inriver	Surrogates	2002	SNAKE3	BON	05/08/2003	2005	H	1	2	M	76
Inriver	Surrogates	2002	SNAKE3	ND	.	2005	H	1	2	M	49
Inriver	Surrogates	2002	SNAKE3	ND	.	2005	H	1	2	F	77
Inriver	Surrogates	2002	SNAKE3	JDJ	04/22/2003	2005	H	1	2	M	71
Sum trans	Surrogates	2002	SNAKE3	GRJ	08/12/2002	2005	H	0	3	M	72
Sum trans	Surrogates	2002	SNAKE3	GRJ	08/18/2002	2005	H	0	3	M	65
Sum trans	Surrogates	2002	SNAKE3	GRJ	08/28/2002	2005	H	1	2	F	74
Inriver	Surrogates	2002	SNAKE3	GOJ	08/05/2002	2005	H	0	3	M	72
Inriver	Surrogates	2002	SNAKE3	ND	.	2005	H	1	2	F	75
Sum trans	Surrogates	2002	SNAKE3	GRJ	09/28/2002	2005	H	1	2	M	74
Inriver	Surrogates	2002	SNAKE3	JDJ	04/09/2003	2005	H	1	2	F	82
Inriver	Surrogates	2002	SNAKE3	ND	.	2005	H	1	2	M	61
Inriver	Surrogates	2002	SNAKE3	MCJ	04/11/2003	2005	H	1	2	F	72
Inriver	Surrogates	2002	SNAKE3	ND	.	2005	U	1	2	F	67

Appendix Table B. Continued.

Migration pathway	Group	Migration year	Release site	Dam	Date	Return year	Origin	AOE	OA	Gender	FL
Sum trans	Surrogates	2002	SNAKE3	GRJ	07/06/2002	2005	H	1	2	F	81
Inriver	Surrogates	2002	SNAKE3	GOJ	08/04/2002	2005	U	0	3	F	76
Inriver	Surrogates	2002	SNAKE3	GRJ	10/13/2002	2005	U	1	2	F	74
Sum trans	Surrogates	2002	SNAKE3	GRJ	07/06/2002	2005	H	1	2	M	67
Sum trans	Surrogates	2002	SNAKE3	GRJ	07/18/2002	2005	H	0	3	F	80
Inriver	Surrogates	2002	SNAKE3	ND	.	2005	H	1	2	F	67
Sum trans	Surrogates	2003	SNAKE3	GRJ	06/16/2003	2005	H	0	2	M	73
Sum trans	Surrogates	2003	SNAKE3	GRJ	06/22/2003	2005	H	0	2	M	70
Inriver	Surrogates	2003	SNAKE3	ND	.	2005	U	1	1	M	56
Sum trans	Surrogates	2003	SNAKE3	GOJ	07/31/2003	2005	H	0	2	M	67
Inriver	Surrogates	2003	SNAKE3	LMJ	07/07/2003	2005	U	1	1	M	68
Inriver	Surrogates	2003	SNAKE3	GRJ	06/06/2003	2005	H	1	1	M	67
Sum trans	Surrogates	2003	SNAKE3	GRJ	06/21/2003	2005	H	0	2	M	62
Sum trans	Surrogates	2003	SNAKE3	GRJ	06/22/2003	2005	H	0	2	M	63
Inriver	Surrogates	2003	SNAKE3	GOJ	08/01/2003	2005	H	0	2	M	75
Fall trans	LGR RAL	2002	LGRRTR	GRJ	09/06/2002	2005	H	1	1	M	73
Fall trans	LGR RAL	2002	LGRRTR	GRJ	09/17/2002	2005	U	1	2	F	79
Fall trans	LGR RAL	2002	LGRRTR	GRJ	10/09/2002	2005	U	1	2	F	77
Fall trans	LGR RAL	2002	LGRRTR	GRJ	09/05/2002	2005	U	1	2	M	76
Fall trans	LGR RAL	2002	LGRRTR	GRJ	09/25/2002	2005	H	1	2	M	67
Fall trans	LGR RAL	2002	LGRRTR	GRJ	09/06/2002	2005	H	0	3	F	75
Fall trans	LGR RAL	2002	LGRRTR	GRJ	09/19/2002	2005	H	1	2	F	78
Fall trans	LGR RAL	2002	LGRRTR	GRJ	10/17/2002	2005	H	1	2	F	77
Fall trans	LGR RAL	2002	LGRRTR	GRJ	09/13/2002	2005	H	1	2	M	80
Fall trans	LGR RAL	2003	LGRRTR	GRJ	09/05/2003	2005	U	0	2	M	71
Fall trans	LGR RAL	2003	LGRRTR	GRJ	09/19/2003	2005	H	0	2	M	73
Fall trans	LGR RAL	2003	LGRRTR	GRJ	09/09/2003	2005	H	0	2	M	66
Fall trans	LGR RAL	2003	LGRRTR	GRJ	10/09/2003	2005	H	0	2	M	61
Fall trans	LGR RAL	2003	LGRRTR	GRJ	09/11/2003	2005	U	0	2	M	68
Fall trans	LGR RAL	2003	LGRRTR	GRJ	10/31/2003	2005	H	1	1	F	69
Fall trans	LGR RAL	2003	LGRRTR	GRJ	10/23/2003	2005	H	1	1	M	65
Fall trans	LGR RAL	2003	LGRRTR	GRJ	10/23/2003	2005	H	1	1	F	70
Fall trans	LGR RAL	2003	LGRRTR	GRJ	10/09/2003	2005	U	1	1	F	69
Fall trans	LGR RAL	2004	LGRRTR	GRJ	10/05/2004	2005	H	1	0	M	47
Sum trans	LGR RAL	2004	LGRRRR	GOJ	06/14/2004	2005	H	1	0	M	45
Inriver	LGR RAL	2004	LGRRRR	GOJ	09/17/2004	2005	H	1	0	M	54
Fall trans	LGR RAL	2004	LGRRTR	GRJ	10/19/2004	2005	U	0	1	M	40
Sum trans	LGR RAL	2004	LGRRRR	GOJ	06/19/2004	2005	H	0	1	M	45
Sum trans	LGR RAL	2004	LGRRBR	GRJ	06/11/2004	2005	H	0	1	M	42
Sum trans	LGR RAL	2004	LGRRRR	GOJ	06/18/2004	2005	H	0	1	M	54
Fall trans	LGR RAL	2004	LGRRTR	GRJ	10/21/2004	2005	H	1	0	M	44
Fall trans	LGR RAL	2004	LGRRTR	GRJ	10/05/2004	2005	H	0	1	M	47
Sum trans	LGR RAL	2004	LGRRRR	MCJ	07/18/2004	2005	H	1	0	M	39

Appendix Table C. Estimated survival*active migration (S) and detection (P) probabilities for wild and hatchery subyearling fall Chinook salmon during 1995-2001. Estimates are from the studies of Connor et al. (2003b) and Smith et al. (2003). The probability of a PIT-tagged juvenile surviving and actively migrating from release to the tailrace of Lower Monumental Dam without being detected at any of the three dams (ND) was estimated as: $(S_{LGR}(1\text{-}P_{LGR}))(S_{LGO}(1\text{-}P_{LGO}))(S_{LMO}(1\text{-}P_{LMO}))$.

Date	Lower Granite Dam		Little Goose Dam		Lower Monumental Dam		P
of release	S	P	S	P	S	P	(ND)
			Wild origin				
05/20/1998	0.708	0.483	0.943	0.636	0.874	0.409	0.065
05/21/1998	0.661	0.434	0.805	0.707	0.853	0.549	0.034
06/02/1998	0.528	0.482	0.845	0.603	0.818	0.449	0.041
06/16/1998	0.356	0.534	0.762	0.586	0.782	0.400	0.025
05/27/1999	0.877	0.390	0.767	0.693	1.000	0.500	0.036
06/02/1999	0.770	0.455	0.841	0.608	1.000	0.431	0.034
06/01/1999	0.812	0.434	0.569	0.626	1.000	0.398	0.037
06/16/1999	0.364	0.624	0.486	0.757	0.755	0.497	0.036
05/09/2000	0.571	0.474	0.891	0.534	0.849	0.366	0.037
05/23/2000	0.534	0.576	0.688	0.686	0.718	0.457	0.037
05/25/2000	0.444	0.642	0.764	0.685	0.641	0.477	0.037
06/06/2000	0.357	0.632	0.494	0.657	0.906	0.366	0.037
			Hatchery Origin				
05/31/1995	0.656	0.477	0.846	0.396	0.792	0.478	0.072
06/07/1995	0.648	0.506	0.840	0.395	0.755	0.531	0.058
06/14/1995	0.596	0.463	0.705	0.432	0.864	0.445	0.061
06/01/1995	0.644	0.474	0.804	0.431	0.871	0.488	0.069
06/08/1995	0.594	0.497	0.907	0.388	0.748	0.514	0.060
06/15/1995	0.594	0.452	0.777	0.431	0.792	0.484	0.059
06/19/1995	0.499	0.494	0.766	0.358	0.847	0.357	0.068
06/27/1995	0.460	0.470	0.650	0.376	0.863	0.286	0.061
07/05/1995	0.388	0.416	0.562	0.256	0.850	0.168	0.067
06/06/1996	0.559	0.612	0.907	0.322	0.727	0.404	0.058
06/13/1996	0.528	0.628	0.925	0.290	0.780	0.345	0.066
06/20/1996	0.391	0.576	0.776	0.267	0.730	0.447	0.038
06/27/1996	0.247	0.569	0.736	0.256	0.668	0.286	0.028
07/03/1996	0.124	0.550	0.425	0.353	0.727	0.333	0.007
07/10/1996	0.054	0.591	0.556	0.200	0.500	0.375	0.003
06/06/1996	0.567	0.579	0.829	0.382	0.819	0.424	0.058
06/13/1996	0.545	0.640	0.794	0.364	0.826	0.393	0.050
06/20/1996	0.362	0.667	0.672	0.343	0.797	0.392	0.026
06/27/1996	0.262	0.537	0.665	0.302	0.633	0.297	0.025
07/03/1996	0.134	0.625	0.298	0.375	0.903	0.385	0.005

Appendix Table C. Continued.

Date of release	Lower Granite Dam S	Lower Granite Dam P	Little Goose Dam S	Little Goose Dam P	Lower Monumental Dam S	Lower Monumental Dam P	P (ND)
Hatchery Origin (Continued)							
07/10/1996	0.063	0.729	0.664	0.255	0.286	0.250	0.002
06/13/1996	0.571	0.576	0.697	0.343	0.701	0.423	0.045
06/20/1996	0.538	0.503	0.476	0.335	0.725	0.348	0.040
06/03/1997	0.573	0.436	0.520	0.555	0.496	0.474	0.020
06/10/1997	0.622	0.429	0.362	0.677	0.785	0.403	0.019
06/17/1997	0.582	0.478	0.529	0.495	0.590	0.473	0.025
06/24/1997	0.488	0.473	0.536	0.577	0.828	0.397	0.029
07/01/1997	0.237	0.515	0.515	0.481	0.489	0.400	0.009
06/03/1997	0.755	0.331	0.302	0.509	0.517	0.433	0.022
06/10/1997	0.595	0.458	0.332	0.563	0.572	0.523	0.013
06/17/1997	0.562	0.489	0.535	0.584	0.579	0.587	0.015
06/24/1997	0.497	0.507	0.583	0.474	0.582	0.505	0.022
07/01/1997	0.310	0.456	0.500	0.507	0.453	0.385	0.012
07/08/1997	0.093	0.606	0.949	0.243	0.077	1.000	0.000
06/03/1997	0.547	0.421	0.343	0.589	0.538	0.515	0.012
06/10/1997	0.390	0.470	0.262	0.586	0.483	0.509	0.005
06/17/1997	0.401	0.457	0.405	0.525	0.595	0.600	0.010
06/24/1997	0.285	0.427	0.345	0.621	0.512	0.633	0.004
07/01/1997	0.195	0.440	0.330	0.375	0.412	0.533	0.004
05/28/1997	0.676	0.390	0.832	0.499	0.738	0.493	0.064
05/30/1997	0.652	0.413	0.827	0.507	0.718	0.494	0.057
06/02/1998	0.502	0.465	0.763	0.658	0.904	0.479	0.033
06/09/1998	0.512	0.521	0.768	0.618	0.963	0.394	0.042
06/16/1998	0.480	0.509	0.740	0.597	0.875	0.392	0.037
06/23/1998	0.236	0.407	0.655	0.570	0.822	0.404	0.019
06/30/1998	0.165	0.466	0.566	0.558	0.909	0.395	0.012
06/02/1998	0.545	0.538	0.768	0.628	0.942	0.443	0.038
06/09/1998	0.517	0.485	0.719	0.660	1.042	0.376	0.042
06/16/1998	0.486	0.477	0.754	0.600	0.806	0.470	0.033
06/23/1998	0.284	0.473	0.714	0.610	0.880	0.407	0.022
06/30/1998	0.249	0.447	0.656	0.502	0.980	0.311	0.030
07/07/1998	0.237	0.440	0.544	0.533	0.794	0.438	0.015
06/02/1998	0.516	0.468	0.709	0.621	0.949	0.428	0.040
06/09/1998	0.595	0.510	0.799	0.585	0.798	0.439	0.043
06/16/1998	0.487	0.496	0.709	0.616	0.966	0.417	0.038
06/23/1998	0.407	0.512	0.697	0.595	0.836	0.424	0.027
06/30/1998	0.382	0.419	0.498	0.571	0.862	0.421	0.024
07/07/1998	0.248	0.410	0.460	0.603	0.800	0.422	0.012
06/04/1998	0.763	0.471	0.822	0.611	0.930	0.392	0.073
06/05/1998	0.658	0.467	0.778	0.601	0.926	0.411	0.059
06/01/1999	0.478	0.370	0.713	0.506	0.695	0.477	0.039
06/08/1999	0.449	0.480	0.630	0.575	1.012	0.309	0.044
06/15/1999	0.250	0.589	0.570	0.526	1.145	0.188	0.026

Appendix Table C. Continued.

Date of release	Lower Granite Dam S	Lower Granite Dam P	Little Goose Dam S	Little Goose Dam P	Lower Monumental Dam S	Lower Monumental Dam P	P (ND)
Hatchery Origin (Continued)							
06/22/1999	0.269	0.610	0.513	0.572	0.832	0.471	0.010
06/29/1999	0.080	0.640	0.428	0.500	0.550	0.545	0.002
06/01/1999	0.394	0.411	0.538	0.682	0.770	0.483	0.016
06/08/1999	0.347	0.439	0.645	0.628	1.179	0.300	0.039
06/15/1999	0.283	0.531	0.470	0.655	0.875	0.413	0.011
06/22/1999	0.220	0.638	0.437	0.524	0.967	0.255	0.012
06/29/1999	0.140	0.620	0.465	0.407	0.593	0.286	0.006
06/01/1999	0.375	0.391	0.621	0.564	0.917	0.362	0.036
06/08/1999	0.285	0.416	0.553	0.576	1.052	0.359	0.026
06/15/1999	0.250	0.526	0.503	0.644	1.002	0.347	0.014
06/22/1999	0.198	0.597	0.477	0.509	0.697	0.415	0.008
06/01/2000	0.152	0.648	0.798	0.632	0.852	0.421	0.008
06/08/2000	0.043	0.536	0.599	0.578	0.584	0.467	0.002
06/15/2000	0.087	0.550	0.648	0.648	0.576	0.514	0.002
06/29/2000	0.037	0.354	0.379	0.500	1.875	0.167	0.007
07/06/2000	0.015	0.579	0.750	0.500	0.667	1.000	0.000
06/01/2000	0.356	0.659	0.775	0.641	0.715	0.452	0.013
06/08/2000	0.193	0.722	0.812	0.568	0.828	0.310	0.011
06/15/2000	0.160	0.645	0.708	0.550	0.755	0.319	0.009
06/22/2000	0.101	0.636	0.713	0.554	0.642	0.479	0.004
06/29/2000	0.053	0.636	0.540	0.822	0.627	0.857	0.000
05/23/2001	0.113	0.647	0.716	0.695	0.865	0.278	0.005
05/30/2001	0.049	0.620	1.112	0.333	0.167	0.636	0.001
06/06/2001	0.020	0.433	0.897	0.524	0.300	0.500	0.001
05/23/2001	0.410	0.675	0.829	0.559	0.592	0.338	0.019
05/30/2001	0.289	0.673	0.828	0.559	0.598	0.342	0.014
06/06/2001	0.121	0.593	0.736	0.427	0.401	0.366	0.005